

QUANTITATIVE EDDY CURRENT VARIANTS FOR MICROMAGNETIC MICROSTRUCTURE MULTIPARAMETER ANALYSIS (3MA)

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INTRODUCTION

Most of the eddy current techniques applied in steel-, machinery building- and automobile-industry for steel grading and microstructure characterization use encircling coils in a differential arrangement. The coil impedance of the test piece is compared with the coil impedance of a "good" masterpiece. The contribution reports recent developments in eddy current testing which contributes with a pick-up-technique to a generalized concept of a micromagnetic structure evaluation (3MA).

PICK-UP-CUP-COIL

In order to use pick-up-coils instead of circumferential coils to characterize steel microstructure states it should be stated, that these sensors should have a good spacial resolution against microstructure changings lateral in the inspection plane and axial into the material depth. By the physical basics to eddy current inspection we know that these microstructure changings only can be detected if they result in changings of the electrical conductivity σ and the initial magnetic permeability μ as far as not additionally an external magnetization is applied. Air-pick-up-coils which can be modeled extremely good [1] are only sensitive against σ - and μ -changes ($1\text{m}/\Omega\text{mm}^2 \leq \sigma \leq 5\text{m}/\Omega\text{mm}^2$, $10 \leq \mu \leq 200$) in the higher frequency range $f \geq 500$ kHz. Unfortunately the impedance changes caused by these (σ, μ) -changes are in the same direction in the impedance plane so that they cannot be observed independently.

In order to overcome the problem a ferrite-cup-coil was developed. Fig.1 shows in the upper part the upright projection of the ferrite cup-coil-kernel and in the lower part the finite-element-mesh which was applied to calculate the coil-impedance and its change with (σ, μ) -changings. For the calculation we have used a computer code, obtained in cooperation with EPRI and developed by W. Lord and R. Palanisamy [2].

Fig.2 shows the advantage of the ferrite-cup-coil related to a conventional air-pick-up-coil. In the upper part the normalized impedance for both types of coils is discussed for one steel specimen ($\sigma = 3.7 \text{ m}/\Omega\text{mm}^2$, $\mu = 86$) as function of the frequency. In the same frequency range the cup-coil has an impedance change which is near five times the change of the air-pick-up-coil. In the lower part of Fig.2 both coils are compared in

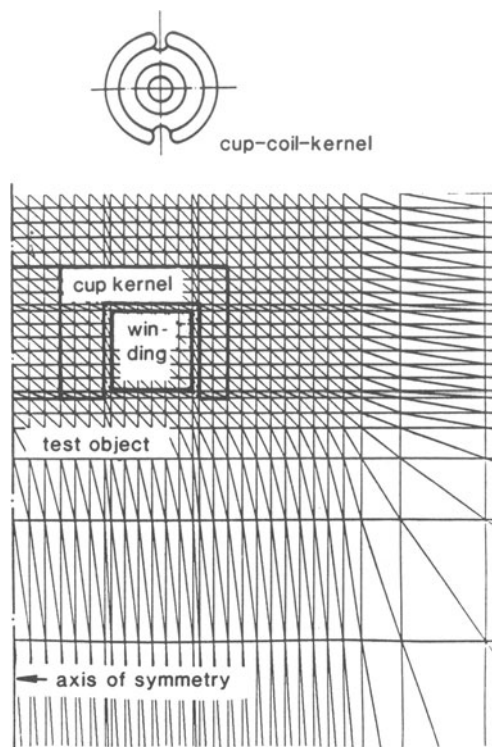


Fig. 1. Cup-coil and FE-mesh for modeling.

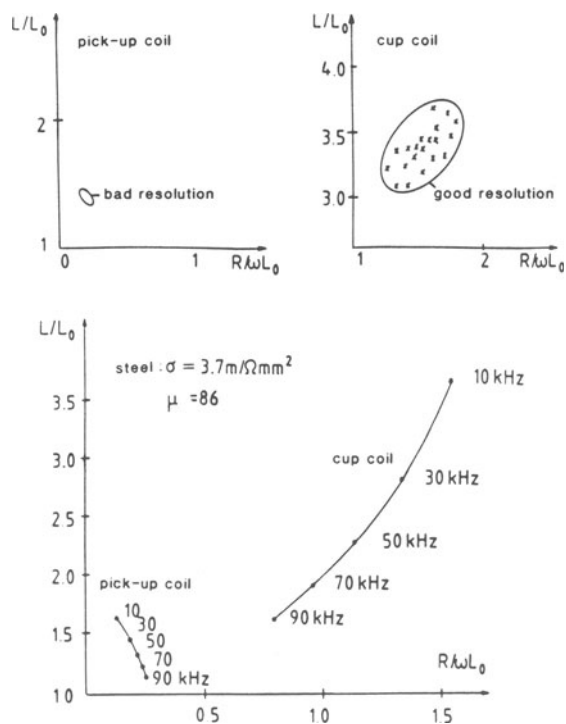


Fig. 2. Comparison: air-pick-up-coil and cup-coil.

order to estimate the sensitivity to separate different steel samples. Even here the advantage of the cup-coil is observed. The reason for this fact is the good magnetic field conduction of the cup-coil whereas a pick-up-air-coil produces large magnetic leakage fields in the air.

(σ, μ) -METER

The finite element modeling has been resulted in a calibration of the cup-coil impedance as function of (σ, μ) -changings for a frequency of 10 kHz. The transformation is a bi-unique-transformation. Fig.3 shows the (σ, μ) -mesh in the impedance plane. The mesh is stored in a table in the storage of a microprocessor-controlled equipment which is called (σ, μ) -meter. The equipment measures the impedance of the cup-coil. By a table-look the (σ, μ) -values are estimated, at which the table values are interpolated. Fig.4 gives a result to a steel grading problem. Three different types of steel can be separated by the use of the (σ, μ) -meter in the (σ, μ) -plane. The scatter in the values represents the allowed scatter in the chemical composition.

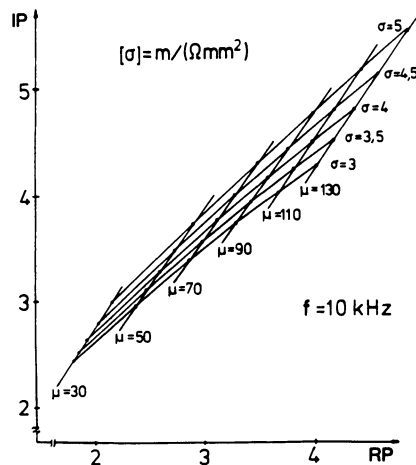


Fig. 3. Bi-unique transformation impedance in (σ, μ) -values.

IMPEDANCE-SPECTROSCOPY

For the detection and characterization of thin near-surface layers an increasing demand can be observed; structure gradients after hardening processes, after decarburization but also after grinding processes should be interpreted. In eddy current testing the frequency dependence of the coil impedance gives the nde-tool to estimate the thickness of the surface layer. Fig.5 shows the example of a magnetic hard layer (thickness $D=50\mu\text{m}$, $\mu_1=50$, $\sigma_1=5 \times 10^{-6}\text{S/m}$) above a magnetic weak bulk volume ($\mu_2=100$, $\sigma_2=\sigma_1$).

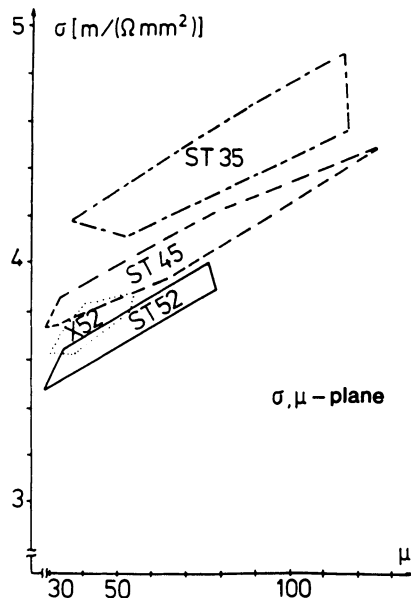


Fig. 4. nd-classification of steel qualities.

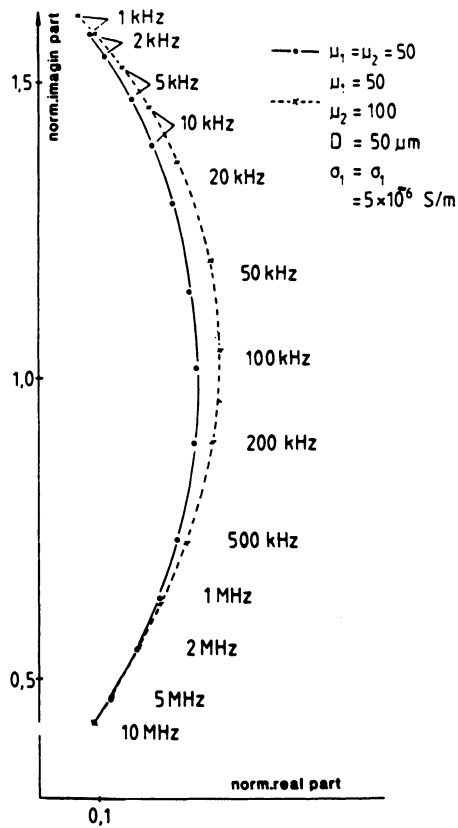


Fig. 5. Frequency dependence of a layered microstructure.

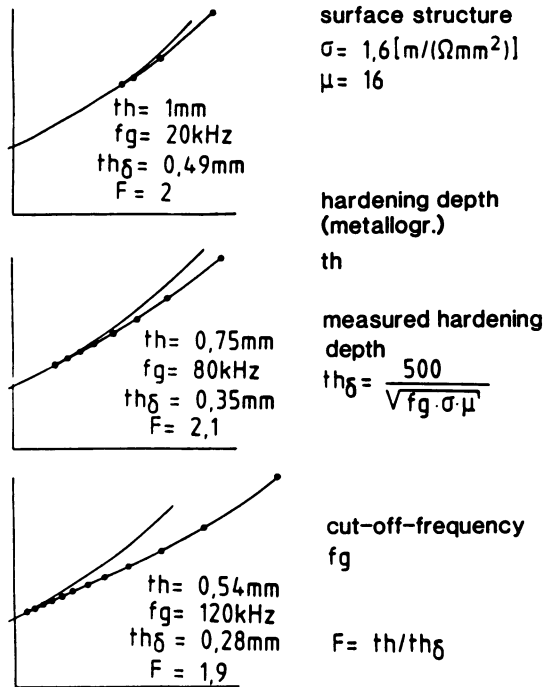


Fig. 6. Impedance Spectroscopy, laser-hardened surfaces.

For the modeling of the impedance-frequency-behaviour the approach in [1] has been used. The dashed curve represents the impedance of the layered structure, whereas the dotted curve is the impedance of a homogeneous magnetic hard microstructure (μ_1, σ_1). The higher the frequency the smaller the penetration of eddy currents. In the high frequency range (2 MHz) the curve of the layered medium matches the reference curve of the hard microstructure, eddy currents exist only in the surface layer. The frequency where this matching starts is determined. Together with the (σ_1, μ_1)-values of the hardened layer ((σ, μ) -meter) this cut-off-frequency results in a penetration depth which correlates linearly with the hardening depth. The factor of proportionality depends on the coil geometry. Fig.6 shows the application on laser-hardened surfaces where this factor has been estimated approx. as 2. The coil is a ferrite-cup-coil.

CONCLUSIONS

Two new eddy current approaches have been presented. The (σ, μ)-meter gives new potential to steel-grading, the impedance spectroscopy allows the characterization of layered microstructures. Both techniques use ferrite-cup-pick-up-coils with higher sensitivity than air-pick-up-coils. Prototype-equipments exist.

REFERENCES

1. C.V. Dodd, C.C. Cheng, W.A. Simpson, D.A. Deeds, and J.H. Smith, The Analysis of Reflection Type Coils for Eddy-Current Testing, ORNL-TM-4107, April 1973
2. R. Palanisamy, Finite Element Modeling of Eddy-Current Nondestructive Testing Phenomena, Dissertation Colorado State University, Summer 1980